

# RESPIRATION IN FISHES:

BY

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*With 4 plates and 21 text-figures*

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## PREFATORY NOTE.

'Respiration in Fishes' was the title of my lecture given at the Indian Museum on the 9th of December, 1932, as part of the series of the Winter Course of Lectures for 1932-33. Every effort was made to treat the subject in a popular way, but at the same time the results of all up-to-date researches on the subject, as well as several new facts and inferences were embodied in it. In consequence, it was thought advisable to publish the matter so as to make it available for the university students and research workers. References to the relevant literature are given at the end with the same object in view. The lecture was illustrated with 44 lantern-slides, but it was not intended to publish a large number of figures, as owing to the serious curtailment of the staff of the Zoological Survey of India and the consequent paucity of artists in the Survey, it was not possible for me to get sufficient illustrations made for this popular article. However, after going through the article Mr. S. H. Prater, Curator of the Bombay Natural History Society, advised me to illustrate it properly so as to increase its usefulness for the general reader. On explaining to him my difficulty, he very generously persuaded the Bombay Natural History Society to make a grant towards the cost of the drawings, most of which are original delineations of specimens and dissections. I am very grateful to the Society and to Mr. S. H. Prater for this help.

The photograph showing the habitat of the peculiar fish *Gyrinocheilus* has been sent to me by Dr. H. M. Smith of the Siam Fisheries and I am indebted to him for permission to reproduce it. The text-figures 7 and 15 are taken from one of my notes in the *Current Science*, and I am thankful to the Editor, Mr. C. R. Narayan Rao, for permission to use the blocks. Similarly, the Director of the Zoological Survey of India has very kindly allowed me to use the blocks of text-figures 9, 13 and 14, which are taken from my papers in the *Records and Memoirs of the Indian Museum*. The text-figure 10 has already appeared in the *Journal of the Bombay Natural History Society*.

As it was not possible to refer to details of structures in a popular lecture, the deficiency has now been made up by giving fairly comprehensive descriptions\* of figures.

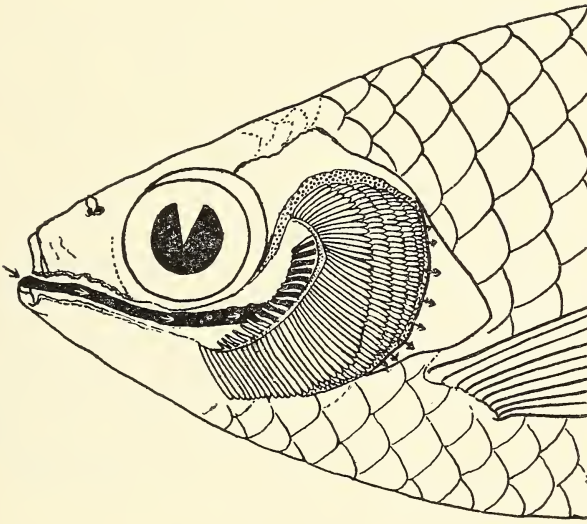
My grateful thanks are due to Lt.-Col. R. B. S. Sewell, Director, Zoological Survey of India, for helpful suggestions and for going through the manuscript. To Babu R. Bagchi I am indebted for most of the illustrations, which he has executed with great skill and care. Mr. D. D. Mukerji has helped me in several ways for which I am thankful to him.

The specimens from which figures in plates 3 and 4 were drawn have been presented to the Bombay Natural History Society.

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\* Dr. Das's paper (16) has proved invaluable in writing up an account of the figures in plates 3 and 4.

Respiration, as we all know, is a physiological process which results in the aeration of blood. The essential feature of this process is the taking in of oxygen and giving up of impurities in the form of carbon dioxide. 'Paradoxical as it may appear, a constant supply of fresh air is as important to a fish as to ourselves, the air being required for its contained oxygen.'<sup>1</sup> There is, however, a great difference in the manner in which oxygen is taken in by a fish and by any higher vertebrate. The land animals breathe the atmospheric air direct, and extract the oxygen from it by means of their lungs, the fishes on the other hand by the use of special organs known as gills, make use of oxygen contained in the air dissolved in the water. This can be demonstrated very easily by



Text-fig. 1.—Dissection of the head from the side of *Barbus (Puntius) sophore* (Ham. Buch.) to show the passage of the respiratory current (indicated by arrows) and the nature and position of the gills.  $\times 4$ .

placing a fish in a vessel containing water from which all air had been expelled either by the action of a pump or by intense heating. The fish will speedily show signs of suffocation and will die of asphyxiation within a very short period. This is true of most of the fishes but there are a few brilliant exceptions which will be referred to later. I have used the word *brilliant* advisedly, for these fishes have made it possible to understand the probable mode of evolution of the terrestrial vertebrates, including man. It may be mentioned in passing that all the higher vertebrates, whether amphibians, reptiles, birds or mammals, possess gill-like structures of one kind or another at some stage of their lives, thus providing a clear proof of their fish ancestry. In a human

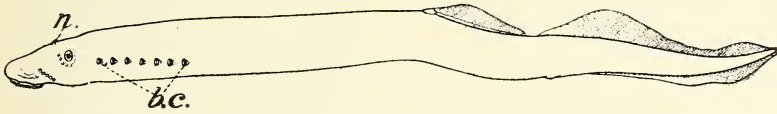
embryo of about 3 to 4 weeks the sides of the throat are provided with four pairs of clefts, which not only correspond in position to the gill slits of a fish, but their supporting skeleton and associated blood vessels provide further resemblances. This fish like apparatus is, of course, never used for breathing, and as development proceeds it becomes modified out of all recognition.

I shall not detain you over the anatomical features of the structure of a gill, but attention may specially be directed to two outstanding facts. In vertebrate animals all breathing organs, no matter what their form, are closely associated with the upper part of the food channel or alimentary canal. Secondly the function of all respiratory organs is to bring the blood in close contact with air, whether free or dissolved in water. For this purpose an extensive area is provided in which blood circulates in small vessels through extremely thin membranes. In this way the chemical properties of Haemoglobin, the red colouring matter of the blood, are brought into play, and result in the absorption of oxygen and the liberation of carbon dioxide. This evening I propose to confine my attention mainly to the mechanism of respiration in fishes, and shall show you the diversity of respiratory surfaces in this group of animals.

The normal mode of breathing in a fish consists of an inspiratory and an expiratory phase. Inspiration is brought about by the action of the coraco-mandibular, the coraco-hyoid and the coraco-branchialis muscles which are attached behind to the pectoral girdle. When they contract, they (*a*) open the mouth, (*b*) lower the floor of the mouth (basihyoid) and (*c*) drag back the branchial arches, thus causing the gill slits to be closed. Now water rushes in freely. Expiration, which follows soon after, is brought about by an opposing set of muscles, the 'lavators' of the mandibular hyoid and branchial arches. These are attached to the back of the skull and the most anterior part of the vertebral column. By their action (*a*) the mouth is closed, (*b*) the floor of the mouth is lifted, thus diminishing the size of the buccal cavity and (*c*) the branchial arches are pulled forward causing them to diverge from one another like the ribs of an umbrella, thus opening the gill sacs and allowing the water in the pharynx to escape to the exterior. These respiratory movements are no doubt responsible for the familiar phrase 'to drink like a fish.' The author of the phrase seems to have erroneously assumed that the regular opening and shutting of the mouth is a proof that the fish drinks. A fish drinks only to expel the water through the gill openings, whereas a man who 'drinks like a fish' takes the liquid in his system. There is another difference also. When deprived of a 'drink' the majority of fishes become 'queer', whereas men become 'queer' when they indulge in the habit of 'drinking like a fish.' There are, however, exceptions to this rule both among fish and men. Some fish can go 'dry' for a short period, and there are surely men who can 'drink like a fish' for sometime at least without any outward effect on their behaviour. So far as actual drinking is concerned, it is doubtful whether a fish drinks at all, for during respiration the gullet is so tightly closed behind the

last pair of pharyngeal clefts that little, if any, water is able to find its way into the stomach.

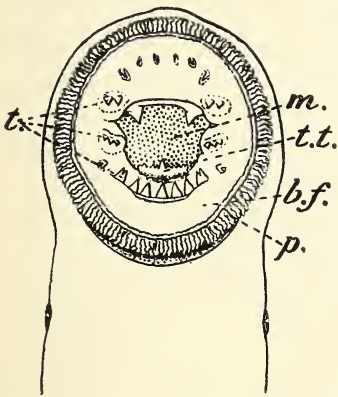
Most of the fishes breathe in the manner described, but there are some which, owing to their peculiar mode of life, have been obliged to modify this process in accordance with change in their habits. The Lamprey, for example, has adopted a parasitic



Text-fig. 2.—Lateral view of the Lamprey-*Lampetra fluviatilis* (Linn.).  $\times 1/3$ .  
*n.*: median nostril; *b.c.*: branchial clefts.

habit, and spends a good deal of its time attached to other fishes by means of its sucker-like mouth. It is obvious that when thus

attached it would be impossible to inhale water through the mouth without losing its hold. The water then is taken in and expelled from the branchial sacs by their external openings through the alternate expansion and contraction of their muscular walls. Freshwater Lampreys use their mouths for holding on to rocks in swift waters. The habits of the related Hag-fish are still more singular, for it bores right into the fish it attacks.



Text-fig. 3.—Ventral surface of head showing suckorial mouth of *Lampetra fluviatilis* (Linn.).  $\times 2$ .

*b.f.*: buccal-funnel; *m.*: mouth; *p.*: papillated margin of funnel; *t.*: teeth of buccal-funnel; *t.t.*: teeth on tongue.

A Skate as judged from the build of its body, is essentially adapted for a life on the sea floor, and consequently its method of breathing has undergone modification. While swimming or crawling about it is able to breathe in the normal manner, but when resting at the bottom there is a grave danger of taking in sand with the stream of water and thus clogging up the delicate gill-filaments. The mouth and the external gill openings are on

the under side of the head, but there is a comparatively large opening behind the eye. This special structure is known as a spiracle. The Skate when resting at the bottom inhales water by way of the spiracle and expels it through the gill openings in the normal manner. Rand<sup>2</sup> and Darbishire<sup>3</sup> have observed the spouting of

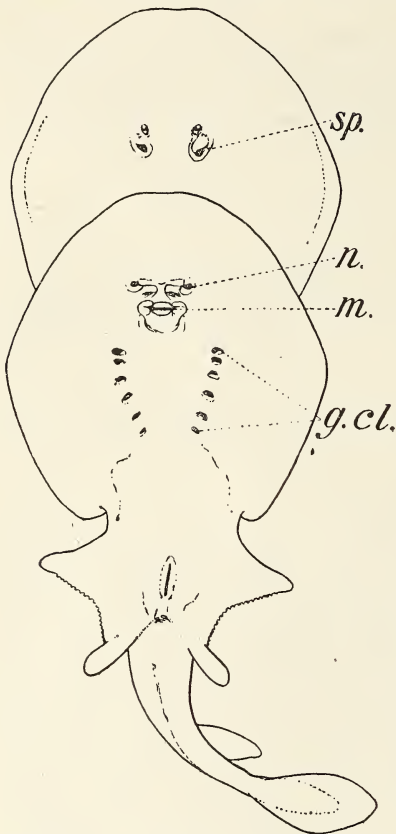


water from the spiracle and concluded that in addition to this causing a respiratory incurrent through the mouth, the fish regularly employs spouting or the spiracular excurrent either 'as a means of keeping the eyes unobstructed' or 'as a means of ridding the pharynx of unpleasant matter'.

In the Trunk-fishes the head and body form a strong bony box and, therefore, the movements of any part of the body are difficult. Thus they are obliged to keep up the flow of water over the gills by a series of rapid panting movements, as many as 180 per minute. The pectoral fins of this fish are supposed to assist in respiration by fanning a current of water through the gill openings by their constant motion. Professor Goode<sup>4</sup> writes: 'when taken from the water one of these fishes will live for two or three hours, all the time solemnly fanning its fins, and when restored to its native element seems none the worse for its experience, except that, on account of the air absorbed, it cannot at once sink to the bottom'.

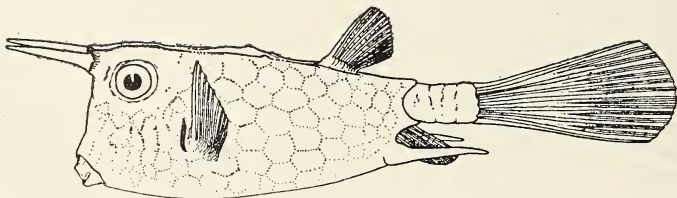
Fulton<sup>5</sup> has observed the reversed action of the gill covers in Plaise. When clinging to the

sides of an aquarium tank with their snouts out of water the current was drawn in from behind through the gill-openings and spouted



Text-fig. 4.—Dorsal surface of head and ventral view of the Skate, *Narcine timlei* (Schn.) Nat. size.

*g. cl.*: external gill-clefts; *m*: mouth; *n*: nostril; *sp*: spiracle.



Text-fig. 5.—Lateral view of the Trunk-fish, *Ostracion cornutus* Linn.  $\times \frac{1}{2}$ .

'as a little fountain, an inch or so in height'. The advantage of such a habit is obvious, as in the circumstances the current cannot be inhaled through the mouth.



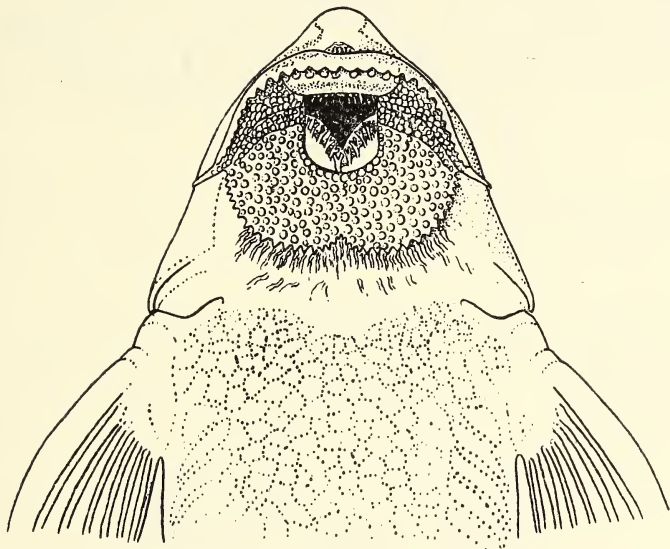
*D. Bagchi photo.*

TORRENTIAL STREAM.





We have so far considered isolated exceptions and seen how the mode of breathing changes with the requirements of the diverse types of fishes. This becomes very clear when entire populations of abnormal habitats, such as torrents and marshes, are taken into consideration. The cold and rapid waters of the hill streams (pl. I) are highly oxygenated and the fish living in them are favourably placed, so far as oxygenation of the blood is concerned, but there are other factors in this habitat which bring about remarkable changes in the mechanism of respiration. In swift currents the fish as a rule lie at the bottom closely adhering to rocks and stones, and consequently their under-surface is



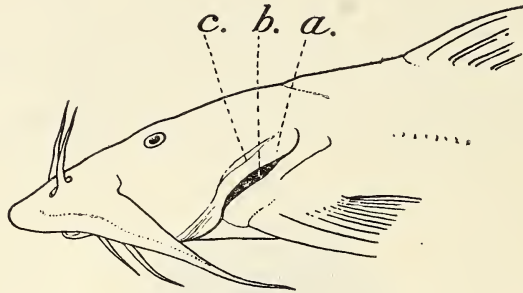
Text-fig. 6.—Ventral surface of head and anterior part of body of *Loricaria strigilata* Hensel.  $\times 2$ .

Notice the broad, papillated lips that are reflected round the inferior mouth and serve as organs of adhesion.

greatly flattened and horizontal. The mouth is usually small, and is situated on the under surface considerably behind the tip of the snout. In some fishes the lips are broad and reflected round the mouth to form adhesive organs. As a result of these modifications the normal mode of breathing would seem hardly possible, and judging from the structure of the *Loricariidae*, Regan<sup>6</sup> believed that when these fishes fasten themselves to stones by means of their sucker like mouth 'respiration seems then to be effected by taking in water through the gill openings and expelling it out by the same passage in a reverse direction'. We have already seen that Lampreys breathe in this way when attached to another fish or a rock by their suckorial mouths. This is, however, not the usual mode of breathing in the hill stream fishes. With the exception of a few species all hill stream fishes inhale water through the mouth and expel it through the gill openings. But in spite of



this the mechanism of respiration is different. It has been observed that during respiration the mouth remains open throughout,<sup>7,8</sup>

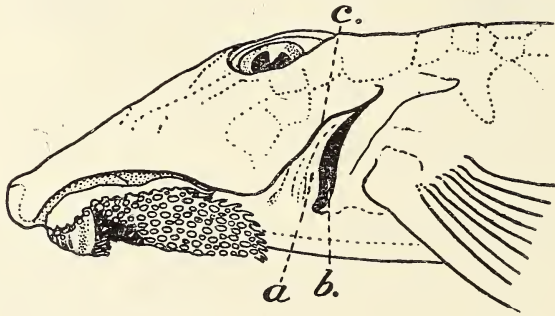


Text-fig. 7.—Lateral view of head and anterior part of body of *Glyptothorax pectinopterus* (McClell.).

(After Hora, *Current Science*, p. 35, 1932).

a: opercular flap; b: gill opening; c: limit of the bony operculum.

and that the respiratory current is initiated and carried on by the vigorous pumping action of the membranous flaps of the gill covers. The current thus set up flows in through the mouth and out of the gill openings. In the Indian hill stream fishes it is the upper



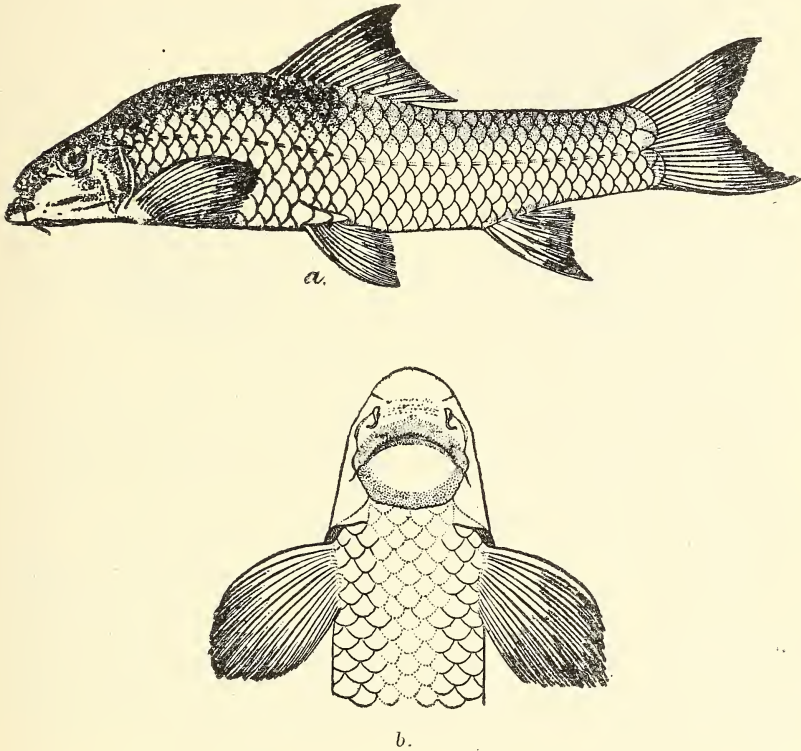
Text-fig. 8.—Ventre-lateral view of head and anterior part of body of *Loricaria strigilata* Hensel.  $\times 2$ .

a: opercular flap; b: gill opening; c: limit of the body operculum.

portion of the opercular flap that performs this function, whereas in *Loricaria*, a South American Cat fish,<sup>9</sup> it is the lower portion that is specially modified for this purpose.

The mechanism of respiration of a typical hill stream fish, such as *Garra*, is like this: the anterior portion of the head is slightly elevated above the substratum and the mouth is kept open. The

upper portion of the gill membrane beats vigorously and pumps out the water from inside the gill chamber. When this happens a further supply of water is sucked in through the open mouth, and thus the respiration goes on. But every now and then, at



Text-fig. 9.—*Garra arabica* Hora.

*a*: lateral view; *b*: under surface of head and anterior part of body.  
(After Hora, *Rec. Ind. Mus.* xxii, p. 678, 1921).

irregular intervals, the entire gill cover is lifted, as if the fish takes a long breath. This movement is probably helpful in ridding the pharynx of obnoxious particles. Another hill stream fish *Balitora* was observed to 'cough' out undesirable particles with considerable force, the object was sometimes thrown out to a distance of an inch or so. The most interesting feature of these fishes is that they are capable of suspending their respiratory movements for a shorter or a longer period, and, I believe, this is helpful in nature when the fish adheres very firmly to rocks. This periodic suspension of respiration is made possible by the fact that the gill openings are greatly reduced so that water can be retained in the gill chambers. The low temperature of the waters of the hill streams and their high oxygenation will also be helpful for this purpose. Moreover, while adhering to rocks by

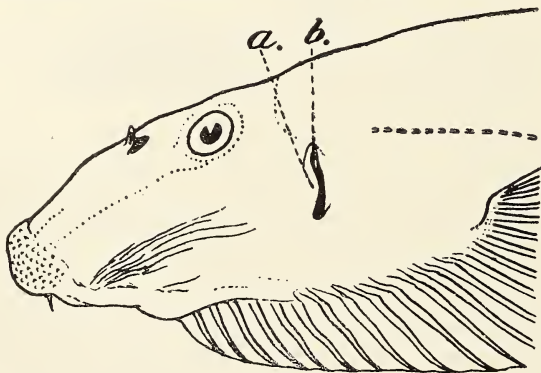
mechanical devices, the fish does not expend much energy, and, therefore, requires a smaller supply of oxygen.



Text-fig. 10. *Balitora brucei* Gray.  
(After Hora, Journ. Bombay  
Nat. Hist. Soc. xxxii, p.113,  
1927).

In a general way I have given the modifications of the hill stream fishes, but to understand them properly it seems advisable to consider the members of one group, *Homalopteridae*<sup>10</sup> for instance. As a result of the flattening of the body, due to the ground habit of life of these fishes, the mouth has gradually shifted from its anterior, terminal position, as in ROHU and CATLA, to a subterminal or inferior situation. For the flow of the inspiratory current definite channels are sometimes developed round the mouth as in *Parhomaloptera*. In most of the *Homalopteridae* there is a broad groove in front of the mouth and the same extends backwards round the corners of the mouth. It seems probable that the groove serves as a catchment area for the water that enters underneath the fish at the anterior end. From this

groove the water flows into the mouth cavity from the corners of the mouth. The number of barbels and tactile papillae that are associated with this groove are no doubt used for testing the inspiratory current. These characters are so important that they distinguish genera and species in the family.

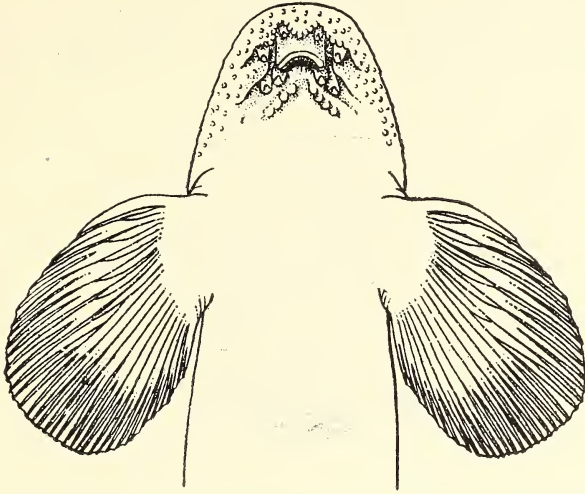


Text-fig. 11.—Lateral view of head and anterior part of body of *Gastromyzon borneensis* Günther.  $\times 2$ .

*a*: opercular flap; *b*: gill opening.

Notice the position of the gill opening, which is small and considerably above the base of the pectoral fin.

In the *Homalopteridae* the gill openings are generally of a moderate size extending obliquely in front of the pectoral fins and

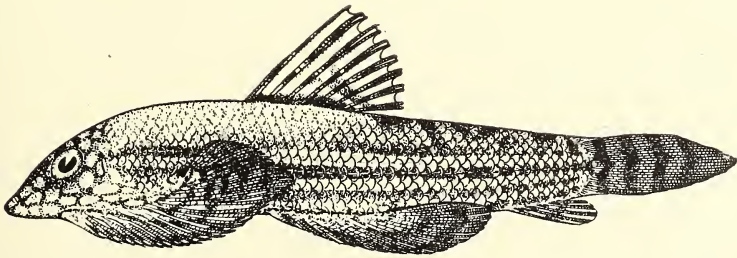


Text-fig. 12.—Ventral surface of head and anterior part of body of *Parhomaloptera microstoma* (Blgr.) to show the nature of the grooves round the mouth.  $\times 3\frac{1}{2}$ .

(Modified after Hora, *Mem. Ind. Mus.* xii, pl. xii, fig. 7, 1932).

on to the under surface for a short distance. It is, however, the upper small portion of the gill opening that functions during respiration. This modification is carried a step further in a number of Homalopterid fishes, in which the gill opening is represented by a small hole above the pectoral fin (text-figure 11). This represents the functional portion of the gill opening, while the lower portion seems to have disappeared altogether.

Among the *Homalopteridae* special mention has to be made of *Sewellia*, a very peculiar fish which I have associated with the



Text-fig. 13.—Lateral view of *Sewellia lincolata* (C.V.).  $\times 2$ .

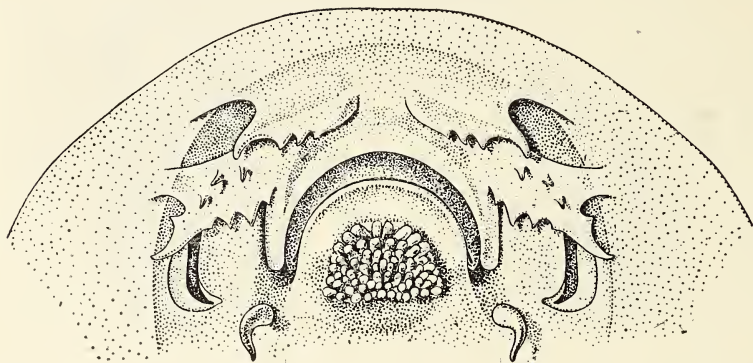
Notice the greatly reduced gill opening behind the eye.

(After Hora, *Mem. Ind. Mus.* xii, pl. xi, fig. 10, 1932).

name of my distinguished chief, Lt.-Col. R. B. Seymour Sewell. The structure of its rostral barbels and the rostral groove is unique



among fishes. Each rostral barbel is plate like at its base and stretches across the rostral groove; it is provided with fringed edges and terminates in a small barbel like process. The bases of the two inner rostral barbels are united with each other, thus forming a floor to the rostral groove in the middle. The most



Text-fig. 14.—A part of the ventral surface of head of *Sewellia lineolata* (C.V.) showing the mouth and the associated structures.  $\times 15$ .  
(After Hora, *Mem. Ind. Mus.* xii, p. 316, 1932).

interesting feature of the fish is that near each corner of the mouth the rostral groove possesses an oval aperture which seems to communicate with the oral cavity. It is, therefore, highly probable that in *Sewellia* the inspiratory current is not taken in through the mouth-opening, but passes directly from the rostral groove through the aperture mentioned above into the oral cavity. The peculiar rostral barbels act as guards to prevent the entry of undesirable objects into the rostral groove.

So far no observations have been made on the living specimens of *Sewellia* and it is a mere surmise that the mouth is not used as an inlet for the respiratory current. In *Gyrinocheilus*, a mountain Carp known from Borneo and Siam, and in *Arges*, a Cat fish of the Andes in South America, it is a well known fact that on account of the peculiar habits of these fishes the mouth no longer serves as a passage for the inspiratory current, and that the gill openings are modified in a remarkable way for this purpose. Each gill opening is divided into an upper slit like portion, which serves as an inhalant opening and communicates with the posterior part of the mouth cavity immediately in front of the gills; and a lower much wider portion which serves as an exhalant aperture and is guarded by a large membranous flap. Vaillant<sup>11</sup> attributed the respiratory movements of this fish to the expansion and contraction of the walls of the oral cavity, but Smith<sup>12</sup> has recently observed the vigorous movements of the opercular or the gill cover flaps—230 per minute. I believe that in *Gyrinocheilus*, as in all other hill stream fishes, such as those that I have discussed already, the





*H. M. Smith, photo.*

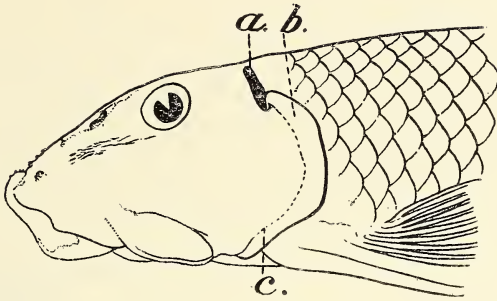
Habitat of *Gyrinocheilus*.



*D. Bagchi, photo.*

Habitat of Indian air-breathing fishes.

respiratory current is initiated and carried on by the opercular flaps of the exhalant openings.

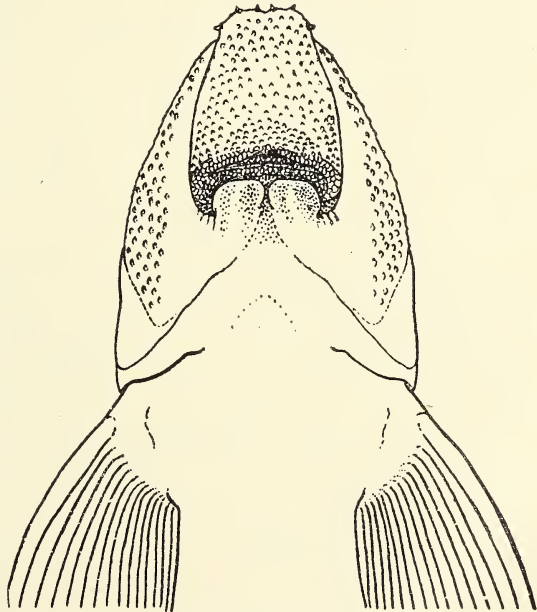


Text-fig. 15.—Lateral view of head and anterior part of body of *Gyrinocheilus kaznakoi* Berg.

(After Hora, *Current Science*, p. 35, 1932).

a: inhalant aperture; b: opercular flap of exhalant aperture; c: limit of bony operculum.

*Gyrinocheilus* is said to feed solely on nutritional matter contained in mud and the lips, which surround the mouth and form a funnel like sucker, are believed to scoop up the mud as well as to enable the fish to cling to stones and other objects. In a typical hill stream (plate II, top-fig.) there is generally no mud to scoop up, and, therefore, I am inclined to agree with Smith<sup>12</sup> who after observing these fishes in an aquarium states that its mouth parts are adapted for scraping algae from stones and other submerged objects. According to him the favourite attitude of the fish, assumed for protracted periods, was to lie in a vertical position against the glass front of the aquarium several feet above the bottom. The mouth, in the circumstances, has become so specialized for attachment that the circulation of water through the mouth



Text-fig. 16.—Ventral surface of head and anterior part of body of *Gyrinocheilus kaznakoi* Berg showing the nature of the mouth and of the associated structures.  $\times 1\frac{1}{2}$ .

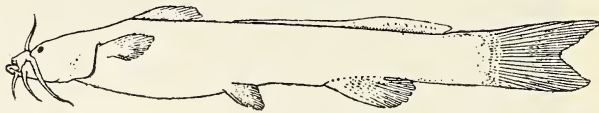
The mouth, in the circumstances, has become so specialized for attachment that the circulation of water through the mouth



has become impossible, and if there were no other means for respiration the fish would have to release its hold in order to breathe. It is to obviate this difficulty that the gill openings have become so peculiarly modified.

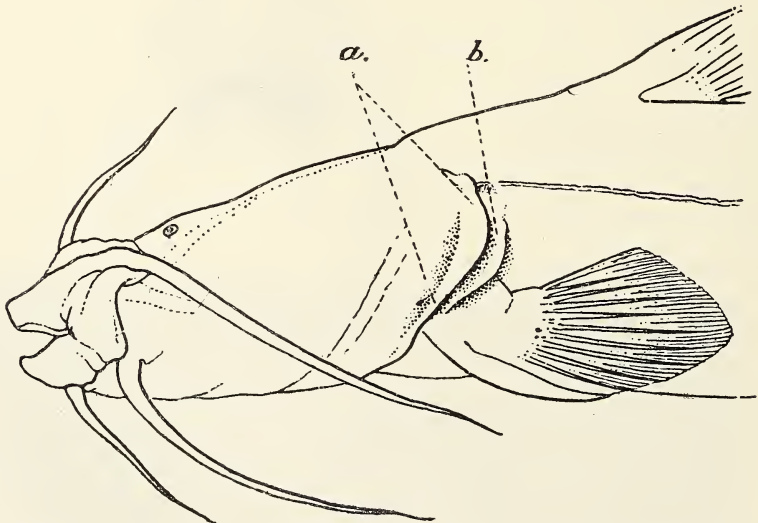
In *Arges* the lips are very broad and reflected round the mouth and it is well known that they are used for fastening the fish to the substratum. So in *Arges*, quite independently of the evolution in *Gyrinocheilus*, the gill openings have become modified in exactly the same way into inhalant and exhalant apertures.

There is one more hill stream fish—*Amblyceps mangois*—to which attention may be directed before passing on to a very differ-



Text-fig. 17.—Lateral view of *Amblyceps mangois* (Ham. Buch.).  $\times 2$ .

ent group of fishes that breathe air directly from the atmosphere. *Amblyceps* lives in small streams at the base of hills and I have studied this fish in its natural haunts in the Sevoke stream in the Teesta Valley below Darjeeling. It is a very variable fish, especially with regard to its tail fin and the adipose fin. It is a voracious feeder, bites viciously and is known to be capable of living out of water for some time. The streams in which *Amblyceps*



Text-fig. 18.—Lateral view of head and anterior part of body of *Amblyceps mangois* (Ham. Buch.).

a: opercular flap; b: flap of skin behind the gill opening.

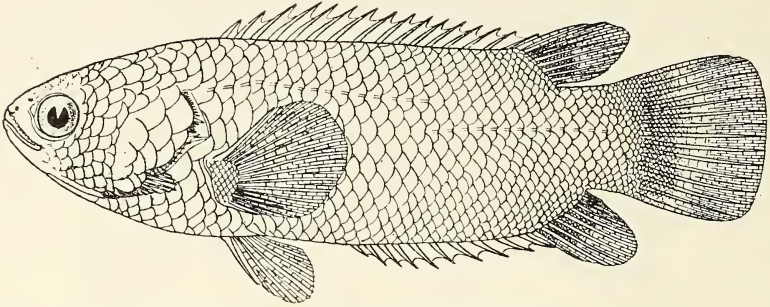
is usually found are liable to become raging torrents after rainstorms, while during the dry months these streams become cut up into a series of pools and puddles. In a torrent it lives at the

bottom among stones and pebbles and breathes spasmodically like most of the other hill stream fishes—the current enters the mouth and is expelled through the upper portion of the gill opening, the membranous flap of the gill cover initiates and carries on the current. Unlike other hill stream fishes, the gill openings of *Amblyceps* are very wide, and consequently a flap of skin is developed behind the gill opening which enables the fish to close the aperture during periods of rest. This structure is not found in any other fish. When the stream begins to dry up, the fish probably wriggles itself into pools.

In all the instances that so far have been studied, there is strong evidence that the evolution or the modification of the respiratory organs in fishes is purposive, and that it is the direct result of the habits of the organisms concerned. We shall now consider the typical air breathing fishes and the circumstances that gave rise to them.

In India we are quite familiar with a variety of air breathing fishes, such as KOI (*Anabas*), MAGUR (*Clarias*), SINGI (*Saccobranchus*), CUCHIA (*Amphipnous*), SAULI (*Ophicephalus*) and others. Our jugglers go about and exhibit some of these fishes walking on dry ground. In this city boat loads of these fishes are imported from outside, and get a ready sale, specially among the Bengali population. They are considered very good for invalids as they are believed to be light, nutritious, strengthening, invigorative and restorative. These are the fishes that are supposed to fall from heaven, for they seem to come from nowhere in ponds and ditches after a heavy shower. The explanation for this is that during the dry season these fishes bury themselves in the mud at considerable depths and aestivate in that condition during the unfavourable season. After a heavy rainfall, when the ground becomes soft, these fishes are awakened from their enforced slumber and come out to populate ponds and ditches. KOI, SAULI and CUCHIA are known to wander from pond to pond in the early hours of the morning. There is a persistent report that KOI is able to climb cocoanut trees, and a young Bengali has described to me how he watched this fish propelling itself along a slanting date palm tree with the help of its gill covers and other parts of its body. I am further informed that shoals of *Anabas* can be seen migrating during the monsoons, and when a slanting tree happens to lie in their way, they begin to climb it as if they were going on land like the other members of the shoal. Of course, the object of climbing is not to eat the cocoanuts. This part of the account may be regarded as a mere fable. In scientific literature the belief obtained currency through the statement of a Danish naturalist, F. de Daldorf<sup>13</sup> who stated to the Linnean Society of London that he had himself seen an *Anabas* in the act of ascending a palm tree which grew near a pond. He further stated that the fish had reached the height of 5 feet above the water, and was going still higher. In the effort to do this, it held to the bark of the tree by the preopercular spines, bent its tail, and stuck in the spines of the anal fins; then released its head, and raising it, took a new hold with the preoperculum higher up. In the Malay language the fish is named the 'Tree

Climber' and in Tamil it is called the 'fish that climbs palmyra trees'. In spite of these anecdotes and observations the tree-climbing habits of *Anabas* were discredited and the Danish naturalist's account was characterized as foolish even by the most



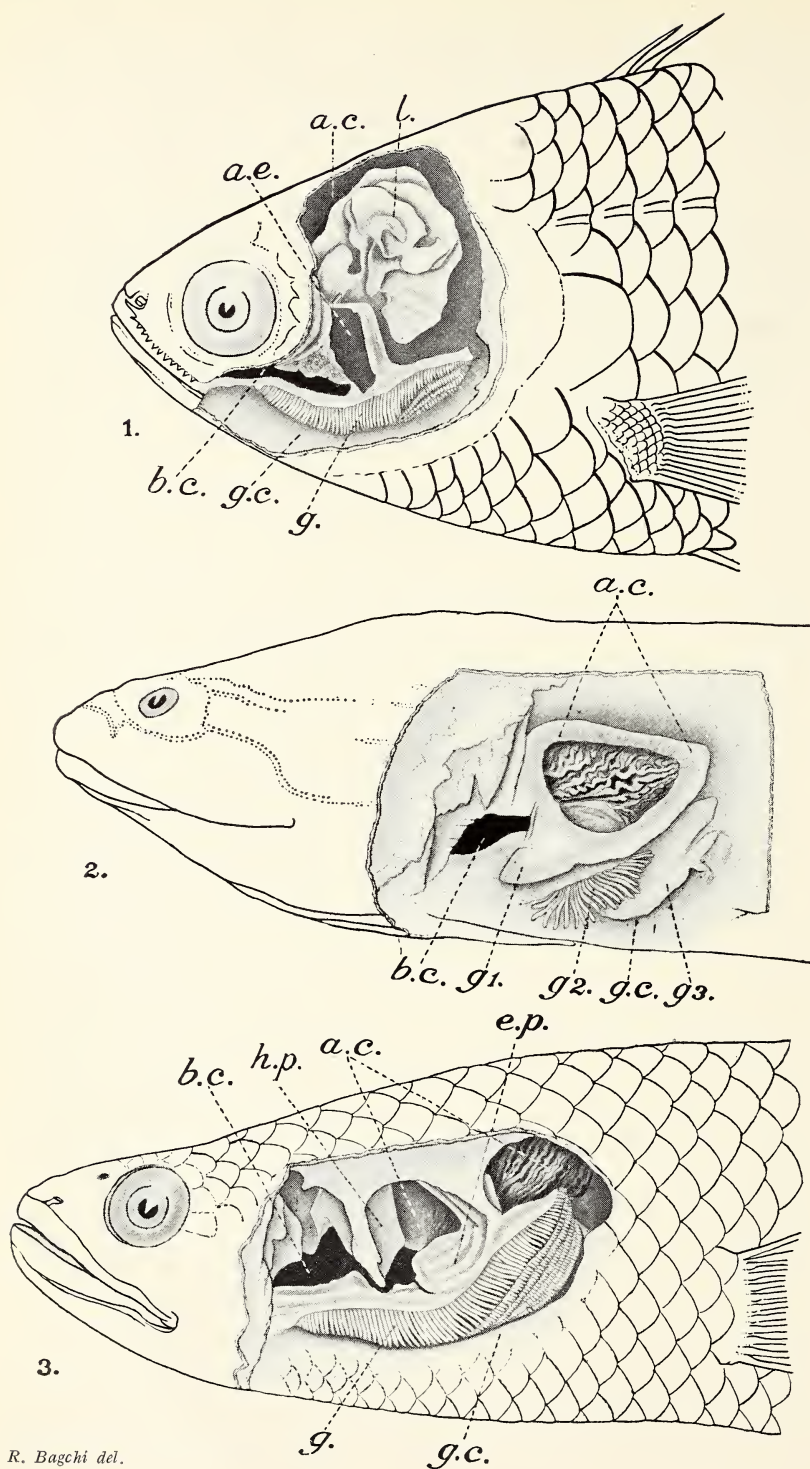
Text-fig. 19.—*Anabas testudineus* (Bloch).  $\times \frac{3}{4}$ .  
The so-called 'Climbing perch' of India.

observant Indian naturalist, Francis Buchanan.<sup>14</sup> According to Buchanan-Hamilton<sup>15</sup> the presence of *Anabas* on trees may be due to the following causes: 'The palm, as is often the case with those of its species (*Borassus flabelliformis*), may have been growing with its lower parts nearly horizontal, and the fish may have then moved along it, as well as on the land; or the palm may have been covered with the knobs, often left by the cultivators when they remove the branches (stipites), and the fish may have been left among these knobs by some bird, and might, no doubt have continued wriggling among them'. Dr. Das<sup>16</sup> does not doubt the fact that these fish are sometimes found on trees, but he thinks that crows and kites probably seize the fish and deposit it high up in the forks of branches of trees to be devoured at leisure. This is expecting too much from our crows and kites, for we know that they will not wait to finish the juicy meal if they happen to seize a fish. Das's explanation, which seems to have been based on Buchanan-Hamilton's surmise, is far from convincing. Dr. Sundara Raj,<sup>17</sup> the Director of the Madras Fisheries, states that one of his assistants was able to demonstrate experimentally that the 'climbing perch' is really capable of climbing 'up a nearly vertical sheet of cloth, when held over the water in the aquarium' in which it was kept. Madaliar and Mitchell<sup>18</sup> also carried out experiments which show the reliability of the early reports. Highly improbable as it may appear, it is likely that *Anabas* sometimes climbs trees accidentally though I have never witnessed a display of its extraordinary scansorial powers.

I hope you will excuse me for having digressed from the subject-matter of my lecture to clear up an interesting point of great biological interest, but my real object was to make it sufficiently clear to you that *Anabas*, when progressing on land or climbing a tree, is apparently like a terrestrial vertebrate breathing air direct from the atmosphere. But if the fish keeps away from







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water for more than 6 to 7 hours, it dies. This may probably explain the fact that dead fishes are found on trees. *Anabas* can climb with the help of its spines, but it can reach the ground afterwards only by dropping down. It is likely, therefore, that some fish after climbing get stranded and die through prolonged desiccation. Water is still very essential for the proper respiration of *Koi*. On the other hand, it is equally true that *Anabas*, as well as other air-breathing fishes, can be drowned by keeping them in water and not allowing them to come to the surface to breathe air. Day,<sup>19,20</sup> and other earlier workers demonstrated this experimentally and recently Das<sup>16</sup> repeated some of these experiments with similar results. Even in highly oxygenated waters these fishes get suffocated. The explanation of this is to be found in the habitat of the fish as well as in its organs of respiration. On lifting a gill cover one sees a chamber situated above the gills and formed as an outgrowth of the ordinary gill chamber (plate III, fig. 1). Each chamber contains a labyrinthiform organ, composed of shelf like plates with wavy edges and supplied with fine blood vessels. When the air is inhaled through the mouth it enters this chamber and the labyrinthiform organ acts as the 'lung' of the fish.

In SAULI (*Ophicephalus*) the accessory respiratory organs are in the nature of two lung like reservoirs in the head, developed as pouches of the pharynx (pl. III, fig. 3). The inner lining of these cavities are richly supplied with blood. The respiratory chambers of CUCHIA (*Amphipnous*) are of a similar nature (pl. III, fig. 2). In this fish the gills are greatly reduced and it seems to have lost practically all its power of aquatic respiration. In MAGUR (*Clarias*) there is an air chamber situated above the gills into which tree like outgrowths project from the upper ends of the gill arches (pl. IV, fig. 3). In SINGI (*Saccobranchus*) a long tubular sac grows backwards from the opercular or the gill cavity and extends as far as the middle of the tail (pl. IV, fig. 1). This sac bears a marked resemblance to the lungs of land vertebrates (pl. IV, fig. 2).

Reference may also be made to some non-Indian air breathing fishes<sup>21</sup>. *Hoplosternum*\* lives in the swamps of the Paraguayan Chaco in South America and uses a part of its intestine as the accessory respiratory organ. The respiratory part of the intestine is thin walled and transparent, and occupies the greater part of the body cavity. In another fish—*Ancistrus*—that lives in company with *Hoplosternum* the large U shaped stomach is always full of gas during life and has been found to serve as a respiratory organ. In *Erythrinus* the central part of the air bladder, which extends throughout the whole length of the abdominal cavity and occupies more than one half of its space, has become lung like, is highly vascular and is consequently red in colour. In the thickness of its walls are cavities similar to those found in lungs.

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\* Excellent illustrations of the habitat and structural modifications of *Hoplosternum*, *Ancistrus*, *Erythrinus*, etc. are to be found in Carter and Beadle's paper referred to in the list at the end.

In *Erythrinus*, it has been mentioned, the air bladder acts as a lung, but the real fact is that the air bladder of our modern bony fishes is a modified or degenerate lung. This conclusion has been reached by studying the structure and habits of an ancient group of fishes, the *Dipnoi* or the real double breathers. The *Dipnoi* are found in Australia, Africa, and South America in marshy places where the water is poor in oxygen. The air bladder is used as a definite lung and the structure of its walls are very much like a vertebrate lung. During periods of drought the fish aestivates in burrows where it forms a cocoon round itself leaving an aperture through which it can breathe air. In their structure the *Dipnoi* are considered to be intermediate between the true fishes and the amphibians, and are no doubt the relics of an ancient group that flourished as early as the Silurian and Devonian epochs. It is strongly believed that animals with the habits and the structure of the Dipnoan fishes made the evolution of the terrestrial vertebrates possible.

In the Silurian and Devonian epochs the conditions were probably very favourable for the evolution of the air breathing fishes and such of their kind that were taking to an absolutely terrestrial life, but later with the arrival of the fish eating reptiles and to several other factors, a large number of them went back to the sea probably for safety. In this environment they found an adequate supply of oxygen for gill breathing and, in consequence, the lungs more or less lost their respiratory function and became either modified into a functionally different organ known as the air-bladder, or disappeared altogether. It is believed that a majority of our bony fishes, both freshwater and marine, are the descendants of those that went back to the sea in the old days. Organic evolution is both progressive and retrogressive. It is further seen how different forms result simply by the modifications of pre-existing structures induced by changes in habits and habitats. It seems probable that fishes with gills and accessory respiratory organs are physiologically better adapted for invading brackish waters than those that breathe by their gills alone, and today most of the freshwater fishes, that are taking to life in brackish waters, are those that are provided with means of breathing air directly from the atmosphere.

Most of the air breathing fishes, in fact all those that we have discussed so far, are found in shallow, stagnant, tropical freshwaters (pl. II, bottom fig.), which are liable to dry up during the dry season. Aerial respiration in fishes seems to have evolved in response to a lack of oxygen in the water, and it is conceivable that periodic droughts provided the stimulus for migration on to the land. There are, however, a few marine fishes that have taken to aerial respiration, and to them, the above explanation cannot be applied. *Periophthalmus*, the well-known mud-skipper, is very common in brackish waters not very far from Calcutta. It spends a considerable part of its time out of water, "walking" or skipping about on the mud flats of mangrove swamps at low tides in search of food. It is also fond of climbing on to the mangrove roots or of basking in the sun perched on a stone in a pool. Some-